QUARTERLY REPORT

(for January - March 1996)

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OCEAN OBSERVATIONS WITH EOS/MODIS:
Algorithm Development and Post Launch Studies

by

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REPORT

I shall describe developments (if any) in each of the major task categories.

1. Atmospheric Correction Algorithm Development.

a. Near-term Objectives:

(i) Continue investigating the effects of stratospheric aerosol and/or cirrus clouds on the performance of the proposed atmospheric correction algorithm. Submit a paper to Applied Optics describing the results of the preliminary study. Determine the suitability of the present strategy for development of an operational algorithm for removing thin cirrus clouds. An operational algorithm will require that we replace our Monte Carlo code by a fast, equally-accurate, radiative transfer code for preparing lookup tables needed for such an algorithm. We will begin development of such a code.

(ii) Investigate the effects of vertical structure in the presence of strongly absorbing aerosols on the behavior of the proposed atmospheric correction algorithm. Develop a strategy for dealing with strongly absorbing aerosols.

(iii) Continue investigating the effects of ignoring the polarization of the atmospheric light field on the performance of the proposed atmospheric correction algorithm.

(iv) Continue examining the suitability of the MODIS SWIR bands for providing information for improving the atmospheric correction.

(v) Develop a detailed model of the diffuse transmittance of the atmosphere as influenced by the angular distribution of subsurface upwelling spectral radiance.

b. Task Progress:

(i) A paper was prepared on our preliminary findings regarding the effects of thin cirrus clouds and stratospheric aerosols on atmospheric correction. This paper was submitted to Applied Optics.

(ii) The atmospheric correction is considerably influenced by the presence of absorbing aerosols. First, the correction algorithm requires a method for knowing when strongly absorbing aerosols are present, and second, it is necessary to know their vertical distribution. It may be possible to use the SWIR bands (see task iv) to identify the presence of at least some types of absorbing aerosols. We are now carrying out a set of simulations aimed at determining the accuracy with which the vertical structure of the aerosol must be known in order to allow a suitable atmospheric correction.

(iii) This study is continuing and we have no new progress to report this quarter.

(iv) No new progress this quarter.

(v) The basic correction algorithm yields the product of the diffuse transmittance t and the water-leaving reflectance. However, it depends on the angular distribution of water-leaving reflectance. If the water-leaving reflectance were uniform, t would be easy to compute, and this approximation has always been employed in the past. However, experimental and theoretical studies reveal that, although the bidirectional effects nearly cancel in the estimation of the pigment concentration using radiance ratios, the water-leaving reflectance can depend significantly on the solar and viewing angles. (Our major task number 3, a study of the in-water radiance distribution, experimentally addresses this problem.) We have initiated a study to understand the effect of bidirectional effects on the diffuse transmittance. Preliminary results suggest that errors of the order of ~2-4% are made in computing t using the assumption that the upwelling subsurface radiance distribution is uniform.

c. Anticipated Activities During the Next Quarter:

(i) Determine the suitability of our preliminary ideas regarding an operation algorithm, and make a decision regarding implementation.

(ii) Analyze the results of simulations to determine the accuracy with which the vertical structure of aerosol is required for correction.

(iii) Simulations described in (ii) above will be used to study polarization effects as well.

(iv) Determine the efficacy of using single scattering to examine the spectral variation of the aerosol reflectance in the SWIR.

2. Whitecap Correction Algorithm.

a. Near-term Objectives:

In order to enhance the database to correlate fractional whitecap coverage with wind speed and air/water temperature, the video image (obtained simultaneously with the whitecap radiometer data, and having a greater field of view than the radiometer) can be digitized so that the quantity of white foam pixels in every video frame can be calculated. Calculating the ratio of white foam pixels to total pixels in every video frame, over a sufficient number of video frame images acquired under the same wind speed and air/water temperature should provide a sufficient database to relate the whitecap coverage to wind speed, etc. This requires the procurement of a video frame grabber and software designed to analyze existing and future data, and we will be investigating this in the next period. Additional sea data will also be acquired, and we will be arranging cruises in appropriate locations

b. Task Progress:

We have just received a video frame grabber to use with the video imagery we have obtained on the last couple of field exercises. The purpose was to enhance our whitecap database to correlate fractional whitecap coverage with wind speed and air/water temperature. The video image (having a greater field of view than the radiometer) would be digitized so that the quantity of white foam pixels in every nth video frame could be determined. Calculating the ratio of white foam pixels to total pixels in the digitized video frame, over a sufficient number of video frame images acquired under the same wind speed, air/water temperature should provide a large expansion of our current database. At this point we are working with the frame grabber, determining the best way to proceed.

In addition at the very end of the quarter we loaded the equipment onto a ship to participate in a cruise of opportunity on the NOAA vessel R/V Malcolm Baldridge. This is a three week cruise from Miami to Miami, but going up near Tampa Bay, FL during the cruise track. As of the end of March the cruise was proceeding very well. It has been windy in Miami, so there should be many opportunities to obtain whitecap data.

c. Anticipated activities during the next quarter:

First of all, the cruise will end during the first month of this quarter so much of this quarter will be spent analyzing the data we obtain during this cruise. In addition we will be using the frame grabber to analyze imagery obtained during earlier cruises to expand the whitecap data base. Finally, while there will probably not be an impact in this quarter, we have contacted several companies operating drilling rigs in the North Sea. One of these companies has come back with a favorable response, so we anticipate that in the near future we will place the instrument on a drilling rig to enable us to get a longer time series, with more stable geometrical setups than can be obtained from a ship. These discussions are continuing at the present time, and we cannot anticipate when these will be finalized.

3. In-water Radiance Distribution Schedule.

a. Near-term Objectives:

Our near-term objective on this task is to acquire data at sea at the next opportunity.

b. Task Progress: None.

c. Anticipated Activities During the Next Quarter: None.

4. Residual Instrument Polarization.

The basic question here is: if the MODIS responds to the state of polarization state of the incident radiance, given the polarization-sensitivity characteristics of the sensor, how much will this degrade the performance of the algorithm for atmospheric correction? We have developed a formalism which provides the framework for removal of instrumental polarization-sensitivity effects.

The difficulty with removing the polarization sensitivity error is that the polarization properties of the radiance backscattered by the aerosol are unknown. Preliminary results suggest that elimination of the polarization effect is possible at the required level of accuracy by estimating the polarization of the top-of-atmosphere radiance to be that expected for a pure Rayleigh scattering atmosphere.

a. Near-term Objectives:

Examine the polarization sensitivity in terms of the amount that can be tolerated using the preliminary correction method that involves only Rayleigh scattering.

b. Task Progress:

Study is currently underway.

c. Anticipated Activities During the Next Quarter:

Complete the study and prepare a report for publication.

5. Direct Sun Glint Correction.

a. Near-term Objectives: None.

b. Task Progress: None.

c. Anticipated Activities During the Next Quarter: None.

6. Prelaunch Atmospheric Correction Validation Schedule.

The long-term objectives of this task are two-fold. First, we need to study the aerosol phase function and its spectral variation in order to verify the applicability of the aerosol models used in the atmospheric correction algorithm. Effecting this requires obtaining long-term time series of the aerosol optical properties in typical maritime environments. This will be achieved using a CIMEL sun/sky radiometer that can operate in a remote environment and send data back to the laboratory via a satellite link. These are similar to the radiometers used by B. Holben and Y. Kaufman. Second, we must be able to measure the aerosol optical properties from a ship during initialization/calibration/validation cruises. The CIMEL-type instrumentation cannot be used (due to the motion of the ship) for this purpose. The required instrumentation consists of an all-sky camera (which can measure the entire sky radiance, with the exception of the solar aureole region, from a moving ship), an aureole camera (specifically designed for ship use), and a hand-held sun photometer. We have a suitable sky camera and sun photometer and have constructed an aureole camera.

a. Near term objectives:

We will install a CIMEL Automatic Sun Tracking Photometer in the Dry Tortugas very soon. We will also reduce the Aureole data and sky radiance data obtained during the October cruise during the next quarter.

b. Task Progress:

During this quarter we installed the CIMEL instrument at Fort

Jefferson in the Dry Tortugas. We have been down once to clean and service the instrument and it appears to be working well and surviving the marine environment very well. There was a very interesting event which was measured and occurred as a cold front approached and passed over the site. The cold front passed during the night, and as result the aerosol optical depth changed rapidly following its passage. Right after the cold front we found that the aerosol optical depth had greatly increased but then slowly decreased throughout the day. We are currently doing assessments on data quality and working on getting a better operational data download. We have been using the sky camera in this quarter, but mainly in polarization mode. This work is supported by ONR and looks at the sky and in-water polarized radiance distribution. It can measure the first three elements of the Stokes polarization vector (Intensity and two linear polarization elements), or the degree of sky linear polarization and plane of polarization.

c. Anticipated activities during the next quarter:

During the next quarter we will be continuing our evaluation of the data quality from the CIMEL system. In addition we will be installing another CIMEL instrument, obtained from Brent Holbren, in Barbados. The intention here is to acquire sky radiance data in an area impacted more heavily by Saharan Dust. This will help with our characterization of African dust, which can often be a major component of the aerosol over the North Atlantic. We will also plan on writing up the sky camera polarization work for publication during this quarter.

7. Detached Coccolith Algorithm and Post Launch Studies (W.M. Balch)

The algorithm for retrieval of the detached coccolith concentration from the coccolithophorid, E. huxleyi is described in detail in our ATBD. The key is quantification of the backscattering coefficient of the detached coccoliths. Our earlier studies showed that calcite-specific backscattering coefficient was less variable than coccolith-specific backscattering coefficient, and this would be more scientifically meaningful for future science that will be performed with this algorithm. The variance of the calcite-specific backscattering has been analyzed for only a few species, thus, we have been examining this in other laboratory cultures and field samples.

a. Near-term Objectives:

With this in mind, the near-term objectives of our coccolith studies this last quarter have been to finalize the revision of several manuscripts which deal with the global distribution of coccolithophores and the optics of calcite. Moreover, we have needed to acquire more bio-optical field data from coccolithophore-rich regions.

b. Task Progress:

I performed activities within four categories this quarter. My first activity was to complete final revisions on three manuscripts related to coccolithophore bio-optics:

Balch, W. M., K. A. Kilpatrick, P. M. Holligan and C. Trees. 1996. The 1991 coccolithophore bloom in the central north Atlantic I- Optical properties and factors affecting their distribution. In press. Limnology and Oceanography

Balch, W. M., K. Kilpatrick, P. M. Holligan, D. Harbour, and E. Fernandez. 1996. The 1991 coccolithophore bloom in the central north Atlantic II- Relating optics to coccolith concentration. In press. Limnology and Oceanography

Balch, W., M. and K. A. Kilpatrick. 1996. Calcification rates in the equatorial Pacific along 140oW. In press. Deep Sea Research

In previous reports, I have described our use of flame atomic absorption to calculate calcite-specific scattering. Unfortunately, we have found this technique somewhat limiting for laboratory experiments in which we sort individual coccoliths. For this, we need to use graphite furnace atomic absorption which is 1000X more sensitive. My technician attended the Perkin-Elmer course on graphite furnace atomic absorption spectrometry this last quarter which will allow us to begin processing our backlog of suspended calcite samples. The course was in Atlanta Georgia during February.

In late March, we participated in a Gulf of Maine cruise aboard the R/V Argo Maine. We took our flow-through light-scattering photometer on this extremely rough cruise, and logged volume scattering due to calcite coccoliths over the three major basins plus Georges Bank. The system also recorded underway temperature, salinity, fluorescence and pH. We took preserved samples periodically for the enumeration of calcite coccoliths and plated coccolithophores. Finally, we measured the production rate of coccoliths using a 14C micro-diffusion technique. Calcification rates were measurable during this cruise which was especially surprising given that this period represented the beginning of the Spring bloom, when diatoms typically dominate. We will process the cell count samples and suspended calcite samples over the coming year.

c. Anticipated Activities During the Next Quarter

With the completion of the above 3 manuscripts, we (myself, Jennifer Fritz (my student) and Emilio Fernandez (former postdoc)) will begin revisions on our continuous culture manuscripts. The papers currently in revision are:

Fritz, J. J. and W. M. Balch. 1996. A coccolith detachment rate determined from light-limited continuous cultures of the coccolithophore Emiliania huxleyi. In revision. J. Exp. Mar. Biol. Ecol.

Balch, W. M., J. J. Fritz, and E. Fernandez. 1996. Calcification rates of Emiliania huxleyi in steady state growth. In revision. Marine Ecology Progress Series.

Fernandez, E., J. J. Fritz and W. M. Balch. 1996. Growth-dependent chemical composition of the coccolithophorid Emiliania huxleyi in light-limited chemostats. In revision. J. Exp. Mar. Biol. Ecol.

These experiments were important to understand the impact of coccolithophore growth rate on coccolith size, integrity and rate of production. Moreover, all of these factors will affect the variance in calcite-specific scattering within any one species. Work on these manuscripts will continue into the next quarter.

We have more sea time obligations in June with another cruise to the Gulf of Maine. This should be a peak time for the abundance of coccolithophores. Following the cruise, there will be considerable data work-up to be done (particle enumeration, suspended calcite measurements, calcification measurements, etc.).

8. Post Launch Vicarious Calibration/Initialization.

a. Near-term Objectives:

We have initiated a critical examination of the effect of radiative transfer on "vicarious" calibration exercises. In particular, we are trying to determine the accuracy with which the radiance at the top of the atmosphere can be estimated based on measurements of sky radiance and aerosol optical thickness at the sea surface. We are carrying out a complete sensitivity analysis of the transfer process including the effects of earth curvature, polarization, sea surface roughness, and calibration error in the surface-based radiometer.

b. Task Progress:

We have completed the analysis, and submitted a paper for publication. Briefly, the radiance at the bottom of the atmosphere (BOA) and the aerosol optical thickness are inserted into a multiple-scattering inversion algorithm to retrieve the aerosol optical properties --- the single scattering albedo and scattering phase function. These are then inserted into the radiative transfer equation to predict the radiance at the top of the atmosphere. Most of the simulations were carried out in the near infrared, where a larger fraction of the top of the atmosphere (TOA) radiance is contributed by aerosol scattering compared to molecular scattering, than in the visible, and where the water-leaving radiance can be neglected. The simulations suggest that the TOA radiance can be predicted with an uncertainty typically less than about 1% when the BOA radiances and the optical thickness measurements are error free. The influence of the simplifying assumptions made in the inversion-prediction process, such as, modeling the atmosphere as a plane-parallel medium, employing a smooth sea surface in the inversion algorithm, using scalar radiative transfer theory, and assuming that the aerosol was confined to a thin layer just above the sea surface, was investigated. In most cases, these assumptions did not increase the error beyond 1%. An exception was the use of scalar radiative transfer theory, for which the error grew to as much as ~2.5%. This suggests that using inversion and prediction codes that include polarization may be more appropriate. The uncertainty introduced by unknown aerosol vertical structure was also investigated and found to be negligible. Extension of the analysis to the blue, which requires the additional measurement of the water-leaving radiance, showed significantly better predictions of the TOA radiance because the major portion of it is the result of molecular scattering, which is precisely known. We also simulated the influence of calibration errors in both the sun photometer and BOA radiometer. The results suggest that the relative error in the predicted TOA radiance is similar in magnitude to that in the BOA radiance (actually it is somewhat less). However, the relative error in the TOA radiance induced by error in optical thickness is usually << the relative error in optical thickness. Presently, it appears that radiometers can be calibrated with an uncertainty of ~2.5%, therefore it is reasonable to conclude that, at present, the most important error source in the prediction of TOA radiance from BOA radiance is likely to be error in the BOA radiance measurement.

c. Anticipated Activities During the Next Quarter:

Investigate the feasibility of developing a inversion-prediction code that includes polarization.

OTHER DEVELOPMENTS

The PI participated in the MODIS Science Team review of MCST on January 23, 1996 at GSFC.

The PI participated in a conference call with MODIS Science Team members and MCST regarding the SBRS MODIS test schedule on March 8, 1996.

The PI and W. M. Balch participated in the MODIS review meeting in Miami from 30 March to 5 April, 1996.

The PI collaborated with Dennis Clark and Ken Voss in the preparation of a detailed plan for validation of atmospheric correction of MODIS ocean bands. This will be presented at the Workshop on Remote Sensing of Aerosols April 15-19 in Washington, D.C. This workshop was organized by Y. Kaufman, D. Tanre, T. Nakajima, and H. Gordon, and is supported by EOS.